Extraction of Chlorophyll-a Concentration Based on Spectral Unmixing Model Using Field Hyperspectral Data in Taihu Lake

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***Abstract*—In China, one of the most common ecological problems of inland water bodies is represented by the eutrophication which diminishes water quality. And the chlorophyll-laden water becomes an obvious sign. Chlorophyll-a concentration measurement is usually used for assessing tropic status of lakes. The development of spectral resolution enables hyperspectral technology possible to monitor water quality successfully, which is based on developing relationships between radiance/reflectance in single band or band ratios and chlorophyll concentration. In this paper, a spectral unmixing model was established based on single-phase field hyperspectral data. And three data types were supported for this model: original data, normalization data and differential data. And selected end-member from known reflectance spectrum, we retrieved chlorophyll-a concentration. The result shows the spectral unmixing model based on differential data gives the best result. Validated this model and shows a good precision and stabilization. Finally, three-phase field hypersptral datum were processed and chlorophyll-a concentration was extracted using the best model. The result shows that spectral unmxing model is a feasible model in the practical application of remote sensing water quality monitoring.**

Keywords- model of mixing spectra; chlorophyll; field hyperspectral data; hyperspectral remote sensing ;

I. INTRODUCTION

In the early ninety-seventies, remote sensing technology was really an effective means in monitoring the quality of waters in streams, reservoirs and lakes due to its high efficiency and periodicity. With the further improvement of spectral resolution, water quality monitoring has transformed from qualitative analysis to quantification analysis. In the past years, the method of water quality monitoring based on developing relationships between radiance/reflectance in narrow bands or band ratios has become successful, such as empirical model, semi-empirical model and so on. Several investigators(e.g., Yu et al.1996, Su et al.2000, Li et al 2002) have developed empirical regression formulas for the evaluation of lake water quality parameters by using spectral ratios.

But in fact water surface-reflectance spectrum is a mixing spectrum because it is affected by multi-parameters of water quality. And mixing spectral model is an successful model for resolving this problem, typically linear mixing spectral model has been used in some field, a good example is geology field. And some papers only have primarily involved this method in water quality monitoring. Thiemann (2000) successfully mapped the Mechklenburg Lake chlorophyll-a concentration distribution by linear spectral unmixing using IRS-1C satellite data. Qian (2003) had efficiently evaluated Dianchi water quality by an approach of improved mixed pixel unmixng.

In this paper we prepare for selecting an optimal linear model for retrieving Chlorophyll-a concentration by using only one day's water reflectance spectra. And validated the selected model by adding another day' s water reflectance spectra. In the last, we retrieved Chlorophyll-a concentration for other past years. The result shows that mixing spectral model is a feasible model in the practical application of remote sensing water quality monitoring.

II. STUDY AREA AND DATA COLLECT

Taihu Lake in china was selected as the study area. In recent years, Taihu area has become an economic center, and also has the largest population. With the rapidly developing economy, the resource and environment has become increasingly worsen, and the water quality degraded. Figure 1 shows the TM image of Taihu.

The water surface-reflectance was acquired using ASD Field Spectrometer, and other auxiliary information such as water sample, GPS location information, water temperature and so on also has been collected.

Figure 1 the TM image of Taihu

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III. Methods

A. Spectral mixing model

mixing Spectrum can be seen obviously in nature, which is composed by lots of pure material spectrum called end-member spectrum. If supposed in the mixture each reflected photon interacts with only one pure surface material, the energy reflected from the materials combines directly. So that each pure material's contribution to the composite spectrum is directly proportional to its content within the mixture. An example has showed in figure 2, which represents a course of spectrum mixing. Two end-member spectra (yellow and blue point) compose a mixing spectrum according on their contents within this mixture.

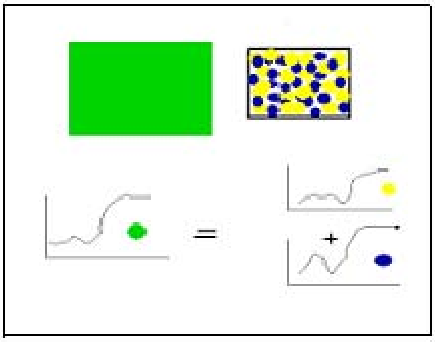

Figure 2 analysis of mixing spectrum

Water reflectance spectrum is also a mixing spectrum, which is contributed within this mixture by all kinds of reflectance of water quality parameters. Linear mixing spectral model is simple and its physical meaning is clear, which has been used in other field successfully. According on this method, we assumed that the water spectral reflectance value is linear combinations of reflectance from a limited set of components. For a given wavelength or channel, the reflectance value of a given spectrum can be expressed using Equation 1:

$$\begin{cases} R_i = \sum f_k r_{ki} + \varepsilon_i \\ \sum f_k = 1 \\ 0 \le f_k \le 1 \\ RMS = \left(\sum (\varepsilon_i)^2 \big/ N \right)^{\frac{1}{2}} \end{cases} \qquad (1)$$

Where N is the sample numbers used for retrieval, R_i is the reflectance observed in wavelength channel i, r_{ki} is the reflectance observed from end-member k in wavelength channel i, f_k is the fraction of the spectrum that is in end-member cover type k, and ε_i is the error for that particular channel. Our purpose is trying to obtain the value of f_k..

B. End-members selected and data processed

The End-member selection is a key technical problem for spectral mixing model. Taihu is a flat lake so the distribution of most of the components is uniform. And we can find the Chlorophyll-a concentration is dramatically varies in spatial distribution (0.0022-0.23059(mg/L)), which represents all kinds of eutrophicaion. So the "highly Chlorophyll-a-laden water" and "pure water" were chosen as spectral end-members (figure 3).

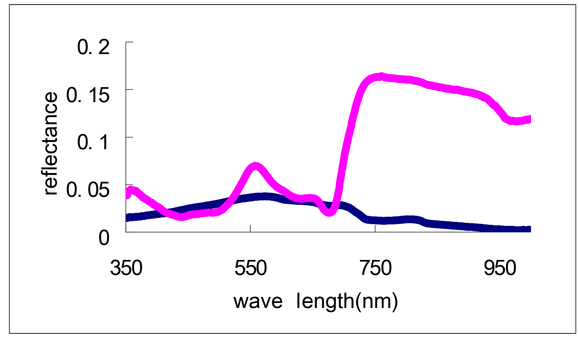

Figure 3 the end-member of spectral mixing model

Two types method: normalization and differential were used for the preprocessing of original reflectance data. Then these two types and original data were input to equation 1 as the source of spectrum mixing.

C. Result

Three types data: original, normalization and differential water reflectance of Taihu lake were input to the spectral mixing model for the retrieval of Chlorophyll-a. The result shows that the spectral mixing model can get good result, and the differential data for the spectral mixing model gave the best result. Figure 4 gives the result based on differential data as the input data of spectral mixing model. And table 1 gives all the result from spectral mixing model.

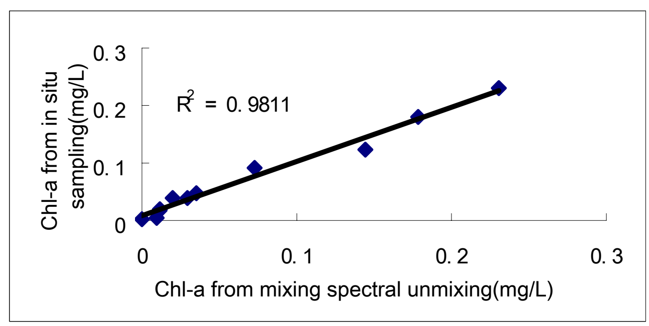

Figure 4 the comparison of Chl-a between differential data retrieved and the lab result

Table1 the RMSE and R^2 of spectral mixing model

	Orig. data	Nor. data	Diff. data
RMSE(mg/L)	0.0195	0.0213	0.0099
R^2	0.9279	0.9093	0.9811

IV. Model Validation

We select the spectral mixing model and the differential data as the optimal model, which was obviously showed its' benefits in retrieving Chlorophyll-a concentration. In order to validate this model's stabilization and precision, we add another day's water reflectance data to this model. The two days we used is very close, and we can think the two days' water condition is mostly uniform. The result shows that the

model has a good stabilization and precision. Figure 5 shows the result of spectral unmixing, and the RMSE of Chlorophyll-a concentration retrieving is 0.0091mg/L.

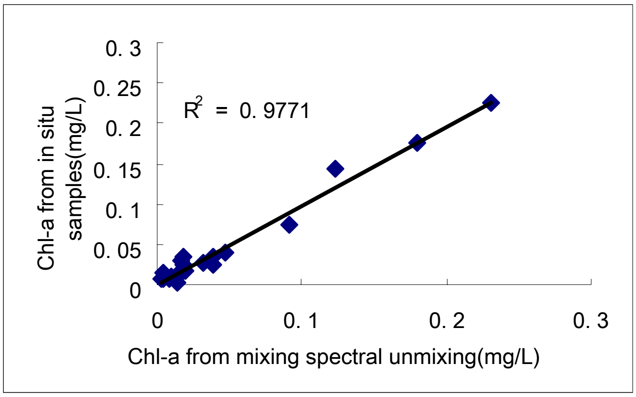

Figure 5 the comparison of Chl-a between differential data retrieved and the lab result

V. THE APPLICATION OF THE MODEL

Based on the model we have disposed the water reflectance data collected separately in 1998, 2000 and 2003 in Taihu. The steps we disposed are as follows:

1) Data processing of three years' data. In order to acquire the three years' differential data, we disposed and put these data as the input data of equation 1.

2) Calculating of spectral mixing model. Using the differential data and the spectral mixing model, combined with the analysis of Chlorophyll-a in lab, we have calculated the concentration of Chlorophyll-a. The comparison of Chlorophyll-a concentration between the result of spectral mixing model and lab analysis has shown in figure 6, which we can obviously find a good relationship between the two results.

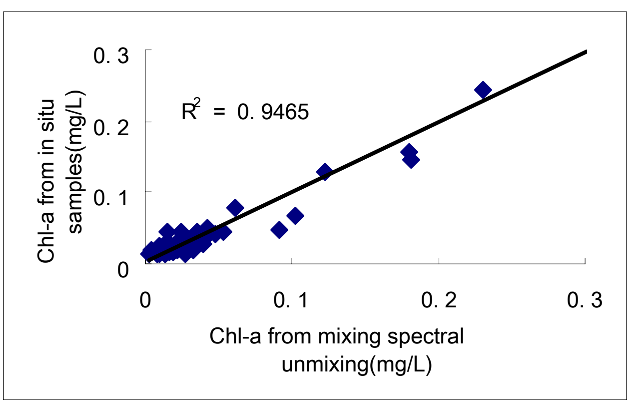

Figure 6 the comparison of Chl-a between differential data retrieved and the lab result

3) Analysis of result. The R^2 between the result of spectral mixing model and lab analysis is 0.9465, which is high linear relationship. And RMSE is 0.0157mg/L, which is lower than empirical model. Three years' different data used in this model and acquired a good Chlorophyll-a concentration retrieving result. Figure 7 shows that we can simulate and evaluate the Chlorophyll-a concentration through spectral mixing model. The result has shown that spectral mixing model is a feasible model and it can fit multi-phase data.

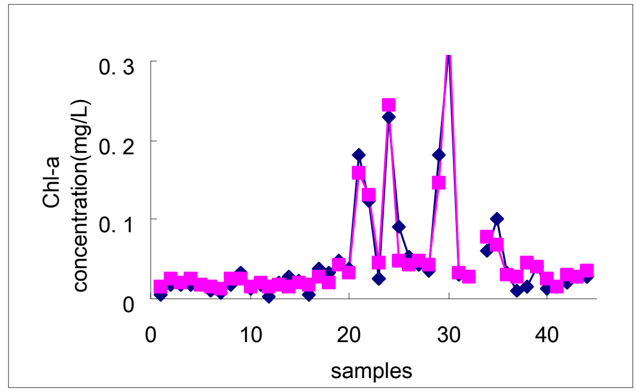

Figure 7 the comparison of Chl-a between spectral mixing model retrieved and the lab result (red color points represent the result of spectral mixing model ,blue color points represent the result of lab analysis)

VI. DISCUSSION

Spectral mixing model is a new method for water quality monitoring. Using differential data as model input data can get the best result. And the spectral mixing model can fit different kind of phase data, and shows a good stabilization and precision for water quality parameters concentration retrieving.

In this paper, only two end-members: water and Chlorophyll-a were considered. Next step more end-members will be considered and an un-linear model will be set up.

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